Repurposing ship steel for construction – opportunities, challenges and the way forward

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Abstract. The construction industry is one of the largest consumers of natural resources and is a significant contributor to energy consumption, waste, and greenhouse gas (GHG) emissions. Steel production accounts for 7% of global GHG emissions, and around half of all steel production is used in the construction industry. Steel is also the primary material used in ships. Norway, with the world's fifth largest fleet, is responsible for the decommissioning of millions of tonnes of maritime steel in coming years. Oppsirk is a research project in Norway that aims to develop new circular business models aimed at upcycling maritime steel into steel products for the construction industry. The aim of this paper is to present the status of upcycled maritime steel use in the Norwegian construction industry, and identify challenges and lessons learnt from pilot projects. This is achieved by interviewing Oppsirk project partners representing the whole value chain. Stakeholders identify sustainability and circular economy (CE) goals, as well as strategic leadership and market competitive values as important drivers for upcycled steel. However, repurposing steel faces several challenges, including technical uncertainty, lack of standardization and documentation, economic viability and market risks, and procurement and regulatory challenges. In conclusion, upcycled steel is an emergent technology, and stakeholders have identified a large scope for further development, including improving market viability, standardising upcycling processes and technical and environmental documentation, clarifying value chain roles in the procurement process, as well as developing knowledge on upcycling and changing traditional mindsets.

Keywords: Circular economy; Steel; Upcycle; Construction; Maritime

1 Introduction

The construction and steel industries are some of the largest consumers of natural resources and are significant contributors to energy consumption (34 % and 8 % respectively), waste, and greenhouse gas (GHG) emissions (37 % and 7 % respectively) [1,2]. In Norway, this corresponds to around 10.5 million tonnes of GHG emissions every year [3]. In recent years, steel production has increased to 1 892 million tonnes each year, whereby around half of all steel production (52%) is used in the construction industry. China dominates global steel production and consumption [2], whilst Norway is a net importer [4]. On average, global steel production has GHG emissions of 1.91 kgCO2e/kg [5]. Typically, primary steel is manufactured using a blast furnace-basic oxygen furnace (BF-BOF), which has high embodied GHG emissions (2.33 $kgCO_2e/kg$). Direct Reduced Iron-based Electric Arc Furnace (DRI-EAF) steel production has lower emissions at 1.37 $kgCO_2e/kg$. In contrast, secondary steel has GHG emissions of around 0.68 $kgCO_2e/kg$ [2,4,5]. The type of energy, type of furnace and recycled scrap content of steel production are the primary factors that affect GHG emissions [6].

Steel is also the primary material used in ships. Norway has the world's fifth largest fleet and is responsible for decommissioning millions of tonnes of maritime steel in coming years. Norwegian shipyards have good health, safety and environmental (HSE) management, but often lose bids due to higher labour costs, tighter environmental restrictions, leading to tighter profitability margins compared to other countries such as Turkey or India [7]. Decommissioned ships exported to Asia are often beached, exposing workers and nature to hazardous chemicals [8]. Recent global political developments have also raised concerns with regards to global supply chains, as illustrated by the recent introduction of import taxes on steel and aluminium to the USA [9].

Upcycling maritime steel from the shipping industry for use as steel products in the construction sector opens for new business models and value chains in Norway. It is expected that upcycled steel, which we mean in this paper as upcycled steel from maritime to construction industry, will have lower primary resource use, lower energy use, and lower GHG emissions than traditional steel production. In Norway, upcycling maritime steel is seen as a disruptive technology that could transform current practices towards a circular economy (CE), potentially positioning Norway as a net exporter of steel and creating jobs that facilitate the transition to more sustainable practices. This study is part of the Green Platform Oppsirk research project [10] that aims to transform the construction industry by upcycling decommissioned ships and oil platforms into construction products such as sheet piles, beams, plates, and modules. This initiative seeks to create a new CE industry in Norway and Europe while strengthening the maritime sector with new value propositions and growth opportunities.

The aim of this paper is to present the status of upcycled steel in Norway, and identify challenges and lessons learnt from pilot projects. The paper focuses on gathering experiences through interviews with Oppsirk project partners involved in these pilots, representing the whole value chain, and summarize the drivers, challenges and opportunities to the use of upcycled steel.

2 Methodology

Semi-structured interviews were conducted via Microsoft Teams between January and February 2025 in Oslo, Norway. In all, ten interviews were conducted with twelve participants involved in pilot projects using upcycled steel products. The interviews lasted between 30 - 60 minutes. An interview guide was developed and distributed to all participants prior to the interviews, covering the following main themes:

- General information: Project overview, environmental goals related to upcycled steel interview object background and role in the project

- Procurement and contract requirements: covering legal and regulatory factors, procurement criteria,
- Challenges and success factors: covering motivations for upcycled steel, challenges encountered, success factors for implementation and priorities for future projects.
- The way forward: suggestions to improve the adoption of upcycled steel, new measures to suppliers and building owners, and opportunities identified through experience

Interview subjects represent the whole value chain (see Fig. 1) and were identified through four pilot projects, see Table 1. Pilot project 1 (P1) was one of the first pilot projects to use upcycled steel. P2 is an innovation concept project and all the three projects, P1, P2 and P3, were funded for testing the upcycled steel as part of innovation projects. P4 is the only pilot project still under construction at the time of interview. Stakeholders were identified from the whole value chain, including: decommissioners, producers, suppliers, consultants, steel workshop manufacturers, contractors, and public and private building owners. See Table 2 for an overview of the stakeholders interviewed, their role, and pilot project involvement.

Table 1. Overview of pilot case studies.

Pilot project code	Type of upcycled steel product used	Project status
P1	Sheet piling in the foundations	Completed
P2	HSQ beam in construction of the load-bearing structure	Completed
P3	I beam in construction of the load-bearing structure	Completed
P4	HSQ beam in the load-bearing structure	Under construction

Figure 1. Value chain for upcycled steel.

Table 2. Overview of the respondent's profile.

Interview (no.)	Respondent code	Role in the value chain	Pilot project
1	R1	Public building owner	P1, P3
2	R2	Public building owner	P2
3	R3	Private building owner	P4
4	R4	Contractor	P1
5	R5	Decommissioner	P2, P3, P4
6	R6	Decommissioner and producer	P1
7	R7	Steel workshop manufacturer /supplier	P2, P3

8	R8	Steel workshop manufacturer /supplier	P4
9	R9	Consultant (two participants)	P1, P2
10	R10	Upcycled steel supplier and consultant (two participants)	P1, P2, P3, P4

The interviews were transcribed and then coded in NVivo v14 qualitative data analysis software [11] to identify patterns, categorize key themes and sub-themes and analyse relationships. Key themes and sub-themes were identified by carefully reading the interviews, grouping similar ideas, refining and organising them into main and sub-themes using NVivo. The key themes and sub-themes were coded, verified and quality assured by two researchers who were present during the interviews. The number of coded references in NVivo for each theme was counted per stakeholder, and an overview was created to illustrate the distribution and relative importance of key themes across the stakeholders based on the coding frequency.

3 Results and discussions

The results from the thematic analysis of the interviews are presented in Table 3 and show the drivers, barriers, success factors and the way forward for the adoption of upcycled steel in the construction industry. Results are organized by theme, sub-theme and stakeholder. These results are discussed in terms of drivers, ambitions and motivations; challenges; success factors; and the way forward.

Table 3. Drivers, barriers, success factors and the way forward identified in interviews for upcycled steel in the construction industry.

Category	Respondents					
	R1, R2 & R3	R4	R5 & R6	R7 & R8	R9	R10
Drivers						
Sustainability and CE goals	13	1	10	6	6	4
Strategic leadership	8	2	5	8	0	3
Market competitive	3	2	6	1	3	7
Technical performance competitive	1	2	1	0	1	3
Collaboration and knowledge sharing	1	1	1	0	1	0
Barriers						
Technical uncertainty	10	5	3	7	1	2
Standardisation and documentation needs	7	2	6	7	3	1
Economic viability and market risks	7	1	3	2	2	7
Procurement and regulatory challenges	5	0	1	8	0	4
Knowlegde development and mindset shift	4	0	3	3	0	1
Success factors						
Collaboration	3	1	0	2	2	0
Financial support	3	3	0	1	0	0
Leadership	2	0	0	2	0	1
The way forward						
Market viability and competitiveness	10	1	8	8	2	3
Standardisation, innovation and documentation	12	1	3	7	2	4
Value chain roles and procurement	8	1	11	5	0	0
Regulations, leadership and incentives	6	1	1	4	0	7
Knowledge development and mindset shift	6	2	2	2	5	0
Geopolitical, environmental and economic impact	1	0	2	0	2	1
Resource availability and sustainability	1	0	1	0	0	1

3.1 Drivers, ambitions and motivations

The top key driver for the implementation of upcycled steel in the construction industry is having **clear sustainability and CE goals**. Stakeholders mentioned GHG emissions, waste reduction, and CE aspects such as the reuse of steel as important sustainability drivers. This is illustrated by the public building owner in R2, who mentioned the potential to reduce environmental impacts, build a local value chain, create local jobs and avoid unnecessary global shipping of steel. Aspirations for scalability and cost efficiency were also identified as important drivers for upcycled steel in pilots P1 and P3 (R1). The ambition of the decommissioning agent (R5) is to provide the best solution for decommissioning with environmental, social and governance (ESG) values and sustainability. With in-house upcycled steel production and recycling capacities, the ambition from R6 is to integrate upcycled steel with lower emissions, while recycling leftover steel in-house and exploring alternative approaches for streamlining paint removal processes.

Strategic leadership is highlighted as a second most frequently mentioned driver. Public building owners (R1 and R2) mentioned a correlation between their organisation's strategies on reducing the carbon footprint from building materials (i.e. setting limit values of 5 kg $CO_{2e}/m^2/yr$ and ≥ 2 % in $kgCO_{2e}$/NOK/year) and the environmental benefits of upcycled steel. R2 expressed that they "*Didn't think about upcycled maritime steel before Oppsirk. It was a positive surprise*". Their goal in the concept project (P2) was to motivate the industry into thinking in new ways. However, they also noted "*we never bought any upcycled steel beam as a product. It was not procured as a product, but as knowledge*". Their involvement has been limited to an innovation project, which uses exceptions from public procurement law, to use innovative procurement, which follows "*three sets of requirements to qualify for this exception:1) it should be new and have a high level of novelty, 2) we cannot pay for the entire project, only up to 80%, 3)its usefulness and benefits from the project should be accessible to society*". The ambition of the private building owner (R3) in the P4 pilot, is that the project prioritises the right timing, cost, and high-quality products, with a focus on using as much upcycled steel as possible. R4's part of R8's organisational strategy is to be in the lead with environment issues. R10's ambition is to provide "*the world's greenest steel, make building products with very low emissions, and change the economy from linear to circular*", and believing that their strategy can yield premium values despite costs.

Market and competitive values are mentioned as the third most frequent driver. For R5, product value and market competitiveness drive the ambition for upcycled steel, creating more value from ships to offset higher decommissioning costs, even though recycling involves lower risk and cost. Market values and storytelling drive R10's motivation. While not everyone is willing to take risks, building owners are influenced by the EU taxonomy, and recognise the need for reused materials. R10's compelling storytelling positions building owners and other stakeholders as the frontrunners in pilot projects, and their narrative inspires others to participate (R2).

3.2 Challenges

Several systematic and practical challenges are mentioned by different stakeholders when implementing upcycled steel. Technical uncertainty is the most cited challenge, particularly by R2, while standardisation and documentation, economic viability, and procurement challenges show varying levels of concern across respondents.

Technical uncertainty is mentioned as the main challenge by building owners, contractor and suppliers, where unknown lifetimes are described as the main concern by R2, and the material weight and reinforcement needs are described as the main challenges by both R2 and R8. R8 mention that the technical properties of upcycled steel vary significantly, as it is sourced from ships constructed under varying maritime regulations, technical requirements, and exposure conditions, which differ from those in building applications. R8 highlighted various challenges encountered during the initial project, particularly those relating to upcycled steel designed for dynamic loads, differing steel qualities to sustain heavy loads, and the complexities involved in removing paint from steel plates. The responsibility for paint removal lay with the upcycled steel supplier, however R8 assisted in identifying optimal paint stripping solutions, including sending the plates to other facilities for more efficient and safe paint removal, since handling paint removal in-house would have been time-consuming and ineffective.

For both private and public building owners, time, cost and quality are the main issues. Uncertainties related to material availability and accessibility are the main concern for R4, with uncertainties relating to on-time delivery of the upcycled steel products to avoid project delays. In the worst-case scenario, the use of ordinary steel products was planned as a back-up in case the upcycled steel was delayed. In addition, the contractor was responsible for checking the quality of the upcycled product and dealing with the challenges relating to thicker products (22 mm) instead of traditional dimensions (16mm). The "*Upcycled steel was too thick to get it down in the soil, and they used a lot more time, and it melted the steel pile aggregate to get it down into the soil*." This resulted in using only 1 of the 3 steel piles delivered to the construction site.

Lack of standardisation and documentation are also mentioned as a major challenge. The need to standardise product documentation is described as the main challenges by building owners (R2), contractors (R4), suppliers (R8) and decommissioners (R5 and R6). R2 highlighted the absence of a national standard for upcycled steel, which raises concerns about the product's remaining lifetime, their impact on loadbearing structures, and the overall weight of the structures. Additionally, the need for more facts on life cycle assessment (LCA) impacts and the identification of projects willing to utilise upcycled steel are mentioned as main barriers. Despite the potential of upcycled steel, it remains in an experimental phase due to the lack of a comprehensive overview of all technical and environmental factors. R3 highlighted the main challenge is that there is a need for approval of steel from the supplier, and that comprehensive documentation from the suppliers is necessary, even though not much time has been spent on this. R3, also highlighted the importance of comparing prices between new and upcycled materials per tonne of CO_2e saved to show how greenhouse gas (GHG) emission metrics can influence construction choices. R6 mentioned a lack of environmental documentation as the main challenge, as currently they have challenges in data collection, understanding how to document the product correctly, traceability, and uncertainties in carbon footprint comparisons for environmental documentation, as this has not been the focus so far.

Economic viability and market risks are the main challenges mentioned by R10. The upfront costs associated with both decommissioning (R5) and upcycled steel supply (R10) are described as a significant risk. The decommissioner pays huge amounts of money to ship owners, and revenue depends on the quality of scrap or upcycled steel products. This process can take years, as it involves decommissioning, removing all hazardous materials, taking the ship down safely, sorting into fractions, and separating the steel for upcycling to maximise recovery. Similarly, R10 faces high upfront costs for various steel types without liability from the decommissioner, which can lead to some products lacking market value. R10 mentioned negative perceptions and regulations not made for upcycled steel which makes the process of optimising steel challenging and expensive. Other challenges from R10 include the contract type for liquification issues and lack of risk allocation, lack of storage, and logistic issues for transporting heavy product around. The cost of steel is also the same regardless of the quality. In summary, R10 summarised "*Cost. Cost. Cost*" as the main challenge.

Procurement and regulatory challenges are described as the main challenge by steel suppliers (R7). R8 pointed to a lack of clear regulatory overview related to upcycled steel, noting they had to take initiatives in navigating standards and defining testing criteria: "W*e have … to … find our own way through the regulations and standards, and … make our own list of criteria*". They described this as a learning curve which could facilitate improving the upcycled steel procurement process in future projects. Although it was time-consuming and costly, R8 expressed optimism "W*e see potential for these projects to go more easily in the future, and we want to use more hours now in learning and become good at it*….[Our] *hope for our next project, [is that] we will have a document that states every step … and what we need to consider before taking on such a project*". Similarly, upcycled steel supplier (R10) highlighted the challenge related to absence of clear regulations for upcycled steel as "*and a linear economy bias".* R10 mentioned that, even if the current regulations do not directly affect upcycled steel, they favor traditional materials, making the adoption of upcycled steel more complex and expensive. Even if small pilot projects face fewer regulatory difficulties, it is challenging to navigate the regulations and work with authorities, especially when scaling up.

3.3 Success factors

The main success factors for upcycled steel have been collaboration and financial support. The open dialogue, effective communication, and **collaboration** with the upcycled steel supplier and consultant were identified as key success factors by most of stakeholders. R2 mentioned having an external driving force and motivation as a key success factor, despite upcycled steel being a new area for them and having limited capacity. This also facilitated a good collaboration between stakeholders in the shipping and building industry. This approach enhances mutual growth through sharing knowledge. R8 stated "*We feel prepared for taking in the steel plates and have a good* *plan for what we need to do and how we need to do it, and we have a good plan for making this a good project*". R7 noted that "*there were no key success factors, it was a success because we made it happen, but the reason it happened is because all the players were somehow reasonable".* R7 also pointed out that the volume of the upcycle steel used was relatively small, keeping the financial risk low. R7 also mentioned "*All of us, except a few, were interested in that it should happen, and most of all the clients wanted it to happen*". The role of building owner (R4) in securing **financial support** for the project, along with collaboration with the consultant and supplier, are highlighted as key success factors in utilising upcycled steel. Getting more experience and pilot projects are mentioned as priorities in the future. R6 also expressed optimism that cost will become less significant over time, particularly if upcycled steel can be produced at a lower expense than traditional steel.

3.4 The way forward

Several aspects are mentioned by different stakeholders for further development, including market viability and competitiveness, standardisation, innovation and documentation, value chain roles and procurement, regulations, leadership and incentives, and knowledge development and mindset shift.

R7 highlights several key aspects to ensure **market viability and competitiveness** of upcycled steel. Pricing is key as "*clients ask for the quality and documentation and then buy it*", making affordability crucial. Optimising materials is also mentioned as vital, "*…if the upcycled steel is a limited resource, then it make sense to use the 16mm steel where you need 16mm steel*". The evolvement of market perception with clear documentation will help quality concerns and marketing strategies, being able to *"...see it, touch it and tell a story...*" to build credibility while avoiding greenwashing is mentioned as equally important. R1 mentions that upcycled steel is seen as promising, especially if it can match the technical quality and reduce costs compared to traditional products. R1 also highlighted mass production could improve technical properties, expand applications, lower costs, and facilitate broader industry adoption. R5 highlighted that ships offer a valuable source of upcycled steel but emphasised that realisation of its market potential requires shifting from traditional scrapping to planned, careful dismantling, and securing buyers upfront to justify costs.

R1 mentioned the need for **proper standard guidelines and documentation,** emphasizing the importance of pilot projects, long term testing, and technical requirements to build confidence in the use of upcycled steel. As R1 stated "*We need more data and pilot projects to get smarter and take a position on this topic*". R2 also highlighted the necessity for additional data and pilot projects to gather more information, enhance understanding, and take a position on this topic. They also highlighted the importance of being at the forefront to lead the sector, ensuring confidence before guiding others, and collaborating with others, as undertaking the project alone can be challenging. R3 highlighted the importance of knowing available steel types, standardising dimensions, as well as early-stage preparation and information sharing within the organisation to support decision making. R8 emphasised that proper documentation, early planning, and awareness of risks such as imperfections in reused materials are important for upcycled steel projects, as they help to eliminate ambiguity in reuse criteria, and enable more standardised decision making. R8 recommended assessing the ground for potential upcycled steel use in projects, ensuring it is soft enough to support the thick steel, or for the upcycled steel supplier to consider a thinner thickness of upcycled steel. R10 highlighted that addressing grey zones in reuse, especially undocumented properties like existing welds the need for research, requires research, testing, and standardization, with early decisions and innovation needed to support CE requirements and break the linear model.

R5 discussed the importance of **supply chain roles and procurement**, describing the current upcycled steel supply chain through middle actors like upcycled steel supplier and consultants and steel factories for inspection, cleaning, and CE marking, but suggested that more of this could happen at the decommissioning facility in the future. R5 emphasised the need for steady supply, streamlined production, and product lines that align with construction industry standards to reduce risk and make upcycling commercially viable. On the other hand, the steel supplier (R7) emphasized that the upcycled steel supplier and consultant should act as a raw material supplier by providing steel plates with standard documentation and a clear price linked to carbon reduction, allowing others in the supply chain to handle production and distribution independently. R8 emphasized the need for clear risk and guarantee allocations, advising for transparent communication between building owners and suppliers about material imperfections and collaboration to support the use of upcycled steel. As R8 put it, "*Everyone should come together to take the risks … and be willing to go a bit away from the book and make it easier for these projects to be carried out*." R1 highlighted that a collaborative contract model (samspillsentreprisekontrakt) is better suited for sourcing upcycled steel and that building owners should be willing to pay more while suppliers improve quality and pricing. R1 also noted the broader potential of upcycled steel, and the need to involve traditional steel suppliers in its development.

Regarding the *future adoption and implementation of upcycled steel*, R8 expressed strong support, stating they are *"very open to using reused steel in future projects and will advise every customer to use reused steel*". The contractor (R4) also indicated interest, noting that they would consider using upcycled steel if timely delivery, manageable costs, and satisfactory quality can be ensured. R8 also mentioned the possibilities of using steel for alternative applications such as telecom structures and temporary construction structures, such as short-term buildings and rigs. While R4 acknowledged higher costs compared to conventional solutions, R4 emphasized that the pilot project supported by government funding and anticipated that costs would decrease with more experience: "*I'm sure it's going to be, maybe cheaper in the future*". R2, on the other hand, clarified that they can only motivate, not mandate, the use upcycled steel. R2 highlighted the need to resolve technical uncertainties, such as the remaining lifetime, fatigue and lack of realistic LCA data, before integrating it in procurement. Although there are no current plans for use in the future, R2 sees potential for upcycled steel in pilot demonstrations. However, R2 noted that not all projects are suitable to use upcycled steel, as their buildings often have unique and complex requirements. R6 also mentioned alternative applications by reusing components beyond steel, such as drains and pumps repurposed into new ships, showcasing a unique life cycle approach.

In terms of **regulations, leadership and incentives,** R10 highlighted the need for clearer regulations, such as GHG limits and reuse KPIs, to drive compliance and adoption of upcycled steel. They acknowledged the role of previous research funding in enabling pilot projects and stressed the need for continued research to support testing and standardisation. R10 also highlighted the importance of funding support, collaboration across the value chain, and integrating upcycled steel as a standard option in procurement. R2 emphasized the state's responsibility to lead by example but stressed the need for certainty before promoting upcycled steel. R2 highlighted the importance of motivation over mandates and mentioned the need for a system to assess circularity before offering incentives. R3 pointed to the value of early involvement in projects and proposed pricing based on CO_2 savings to make upcycled steel more competitive and appealing to building owners. Similarly, R7 supported pricing based on CO_2 savings and suggested government support to help building owners cover initial costs. R10 added that as regulatory pressure increases and the narrative around upcycled steel strengthens, market value will increase, making a shift where regulations compensate for the need for constant communication. As R10 put it "*High regulatory and high story value will give a high market value*."

With regards to **knowledge and changing mindsets**, R9 highlighted success with upcycled steel depends on creativity, understanding material limitations, and being open to new applications. R9 also emphasised the need for experience, flexibility in design, and better knowledge of material history and properties to build trust and enable broader use over time. R2 pointed out that psychological barriers still exist, as many wouldn't naturally consider using upcycled steel. R3 emphasised the importance of early involvement, internal knowledge-sharing and treating upcycled steel like new steel to shift mindsets and highlighted that future projects could benefit from better planning and awareness of available materials. R1 added the importance of learning from those with experience and choose projects where upcycled steel offers the greatest environmental benefits and is economically feasible. R8 highlighted the importance of supplier and customer agreement on setting clear goal and ensuring alignment on expected outcomes.

4 Conclusions

This article has interviewed Norwegian stakeholders in the whole value chain for upcycled steel from maritime ships to applications in the building and construction industry, and identified drivers, barriers, success factors and the way forward. The main drivers for implementing upcycled steel are clear sustainability and CE goals, strategic leadership, and market and competitive values. This is supported by success factors such as good collaboration across the value chain, financial support, and strong leadership. However, several barriers exist including technical uncertainty, lack of standardisation and documentation, economic viability and market risks, as well as procurement and regulatory challenges. Upcycled steel is an emergent technology, and stakeholders have identified a large scope for further development, including improving market viability and competitiveness, standardising upcycling processes and technical and environmental documentation, clarifying value chain roles in the procurement process, having clear regulations, leadership and incentives, as well as developing knowledge on upcycling and changing traditional mindsets. Next steps will involve moving from individual pilot projects to wide scale implementation.

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